Application of Adaptive Time-frequency Analysis in Cardiac Murmurs Signal Processing

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***Abstract*—In order to avoid the disadvantage of low resolution of fixed-kernel time-frequency(TF) analysis, adaptive TF analysis is employed to classify cardiac murmurs including systolic murmur, diastolic murmur. The analysis results of several cases of heart disease with different cardiac murmurs indicate that the TF spectrum based on adaptive cone-kernel distribution is capable to show the power spectrum of cardiac murmurs in TF plane and the dynamic course.The TF resolution is high and the characteristics of different kinds of murmurs is obvious.**

***Index Terms*—Cardiac Murmur, Time-frequency Distribution, Adaptive**

I. Introduction

Cardiac murmur is a long series of synthetic oscillations with different amplitudes and frequencies. Produced in cardiovascular system under both of physical conditions and pathological conditions, some of murmurs are typical symptoms of very kinds of cardiovascular diseases.

The TF characteristics of simulated cardiac murmurs is analyzed by quadratic TF distribution [1]. TF spectrum is made by cone-kernel distribution, as well as, typical murmurs are classified in [2]. In these studies, TF analysis of fixed-kernel function is employed, while, any fixed-kernel TF method has its fixed kernel function, fixed pass band and non-pass band, or auto-component power is found in the non-pass band [3]. No adaptive calibration is done with the change of signal by fixed-kernel TF description. Thus, for very kind of signal, only one TF analysis method can suppress the intertwist and enhance the auto-component, as well as, show the acute TF distribution [4]. In application , high TF resolution can not be obtained by fixed-kernel TF distribution, because cardiac murmur belongs to instable random signal. With the regards of these problems, adaptive TF distribution method has to be studied to present signals with different features clearly.

II. Method

The cardiac murmurs signals used in our experiment come from the heart auscultation tape made by the Department of Medicine of Beijing Second Medical College and the Cardiovascular Center of Beijing Xuanwu Hospital, which is played by SHARP-8000 Hi-Fi recorder. The signal are amplified by an amplifier, whose pass band is 10~2000Hz, which is a wide range for cardiac murmurs. HY-6040 A/D converter(passing rate 10 kHz; converting accuracy 12Bit, Beijing Hua Kang Technology Co. Ltd.) is used to digitalize the signals. The sampling rate is programmably controlled within a range of 0~10kHz. The digitalized murmurs are stored in hard disc for use. The experiment system is shown in Fig.1.

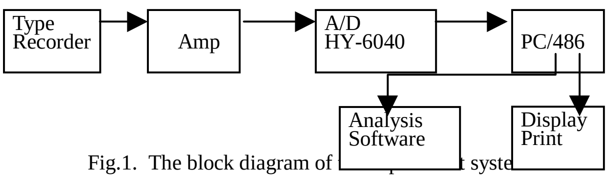

Fig.1. The block diagram of [illegible] syste

In this experiment, according to the principles of hemodynamics, the murmurs of 28 patients are classified as follow: systolic murmur including mesosystolic ejection-type murmur and pansystolic regurgitant murmur; diastolic murmur including diastolic filling murmur, late diastolic murmur and diastolic regurgitant murmur.

III. Analysis

First of all, we present the theories of adaptive cone-kernel distribution, then we use them to analyze the TF features of complex cardiac murmurs.

Discrete cone-kernel distribution is as follow:

$$CKD(n,\omega)=\sum_{k}\Phi_T(n,k)R(n,k)e^{-jk\omega} \qquad 1$$

$$R(n,k)=\sum_{p=-|k|}^{|k|}x(n+p+k)x^*(n+p-k)$$

$$\Phi_T(k)=e^{-4k^2/T^2},-T\le|k|\le T$$

In this equation, $x(n)(n=0,1,...,N-1)$ is the signal. Generally, the feature of CKD depends on the cone-kernel length $T(T\le N)$. To obtain a good result of TF distribution, small Ts are selected for quick changing signals and big Ts for soft signals, incompetent T will reduced the TF resolution of CKD, and the TF power distribution will be scattered. Thus, we have the concentrating rate of power in the TF distribution as the criteria to optimize T. The power of the signal is

$$(e_T^n)^2=\sum_{m=n-N/2}^{n+N/2-1}\int_\omega\left|\sum_{k=-T}^{T}\Phi_T(k)\sum_{p=-|k|}^{|k|}x(m+p+k)x^*(m+p-k)e^{-jk\omega}\right|^2 d\omega$$

$$=\sum_{m=n-N/2}^{n+N/2-1}\sum_{k=-T}^{T}\left|\Phi_T(k)\sum_{p=-|k|}^{|k|}x(m+p+k)x^*(m+p-k)\right|^2$$

$$=\sum_{k=-T}^{T}\Phi_T^2(k)[\sum_{m=n-N/2}^{n+N/2-1}\left|\sum_{p=-|k|}^{|k|}x(m+p+k)x^*(m+p-k)\right|^2] \qquad 2$$

so,

$$E_n(k)=\sum_{m=n-N/2}^{n+N/2-1}\left|\sum_{p=-|k|}^{|k|}x(m+p+k)x^*(m+p-k)\right|^2$$

then, $$(e_T^n)^2=\sum_{k=-T}^{T}\Phi_T^2(k)E_n(k) \qquad 3$$

with the principles of optimation

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$$\max_T C_T(n) = [\sum_{k=-T}^{T} \Phi_T^2(k) E_n(k)] / A_T \qquad 4$$

the power of kernel function is $A_T = \sum_{k=-T}^{T} e^{-4k^2/T^2}$.

$C_T(n)$ is the ratio of the power of TF distribution and the power of kernel function at time n. The T corresponding to the max $C_T(n)$ is the optimal length of cone kernel, which is presented as T_{opt}^n. Thus the adaptive cone-kernel TF distribution is

$$CKD(n,\omega) = \sum_{k=-T_{opt}^n}^{T_{opt}^n - 1} e^{-4k^2/(T_{opt}^n)^2} [\sum_{p=-|k|}^{|k|} x(n+p+k)x^*(n+$$

(5)

IV. RESULTS AND DISCUSSION

In this experiment, each sample of cardiac murmurs is analyzed based on 1024 points, and the TF spectrum of cardiac murmurs with different characteristics are obtained. The result indicates that the features of peaks in the TF spectrum of different kinds of cardiac murmurs is obvious, which are discussed as follow:

A. Systolic murmur

Systolic murmurs are classified into two types according to hemodynamic principles: mesosystolic ejection murmur caused by blood flows from heart to big artery; pansystolic regurgitant murmur caused by valve lesion.

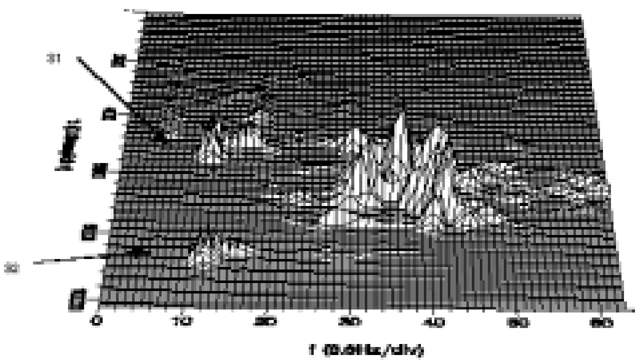
Mesosystolic ejection murmur is caused by blood flows from heart to aorta or pulmonary artery. The TF distribution of murmurs caused by semilunar valve stenosis is shown in Fig.2(a). The spectrum begins after S_1, ends before S_2, but does not reach S_1 and S_2; the frequency range is mainly between 220 Hz and 440 Hz; Three peaks appear at 320 Hz, 375 Hz, 550 Hz; in spite, some frequency components appear around 550 Hz, which proves the clinical research led by Donnerstein et.al[5] about the murmur caused by valve lesions .

The abnormal regurgitation or shunt from high pressure chamber to low pressure chamber during ventricular systole results in pansystolic regurgitant murmur. Fig.2(b) shows the TF distribution of the murmur caused by mitral valve incompetence. The spectrum occupies whole systole, mainly between S_1 and S_2; the frequency extends over a wide range of 250 Hz ~ 640 Hz; distributing evenly, the peaks are not high.

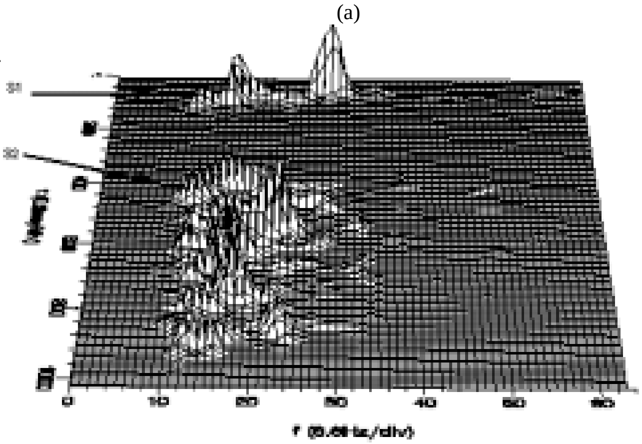
B. Diastolic murmur

Diastolic murmurs are classified into 3 types by mechanism: diastolic filling murmur; late diastolic murmur; diastolic regurgitant murmur.

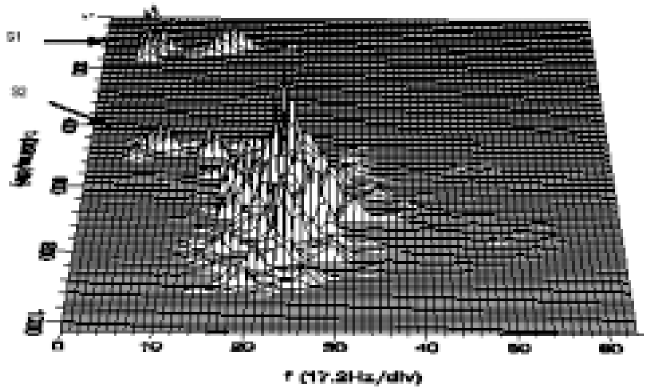
Diastolic filling murmur results from blood flow through abnormal atrioventricular valve during rapid filling period of ventricular diastole. Fig.2(c) shows the TF distribution of

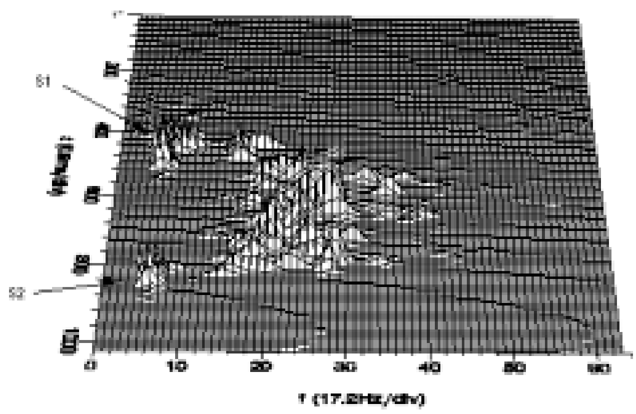


(a)



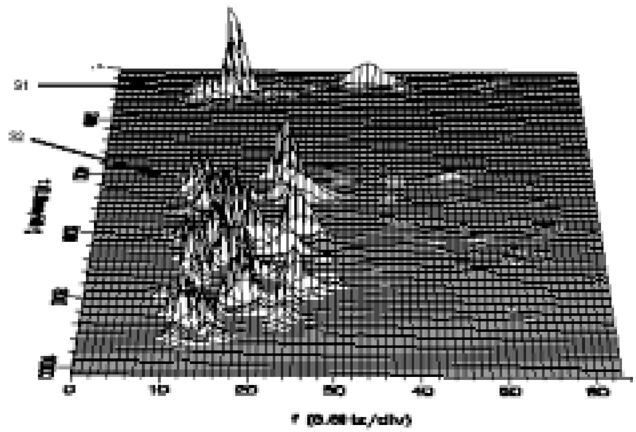
(c)





(b)

(d)



(e)

Fig.2. Time-frequency distribution of cardiac murmurs. (a) The murmurs of semilunar stenosis. (b) The murmurs of mitral insufficiency. (c) The diastolic congested murmurs of mitral stenosis. (d) The late diastolic ejective murmurs. (e) The diastolic recurrent murmurs of pulmonary arterial insufficiency.

diastolic filling murmur caused by mitral valve stenosis. The murmur appears shortly after S_2. The frequency is within a narrow range of 80 Hz ~180 Hz low frequency. The magnitude is medium and appears a trend to increase.

Late diastolic murmur: in late diastole, blood flows in the ventricle push back the mitral valve, the valve shrinks, at the same time, the atrium contracts, the accelerated flow through the valve result in ejection murmur.

The TF distribution is shown in Fig.2(d), The frequency mainly distributes in the range of 75 Hz ~ 250 Hz; several peaks are found around 110 Hz ~145 Hz, however, the peaks appear alternately.

Diastolic regurgitant murmur results from blood flows from high-pressure arteries to low-pressure ventricle because of semilunar valve incompetence in ventricular diastole. Fig.2(e) shows the TF distribution of diastolic regurgitant murmur caused by the pulmonary valve incompetence .The characteristics in time domain is that the murmur begins early and lasts through the whole diastole. The characteristics in frequency domain is that the frequency distributes in the range of 220 Hz ~ 570 Hz high frequency; the peaks are high, however, the trend is decreasing.

V. Conclusion

Improved from the hemodynamic classification analysis of cardiac murmur, adaptive TF distribution is employed to do this job. The results of the experiment indicate that this method can multidescribe the characteristics of cardiac murmur in time domain, frequency and power spectrum, TF resolution is high, and dynamic characteristics are shown acutely.

TF spectrum shows the power distribution and dynamic course of cardiac murmur in TF plane, which offers more information than classical spectrum analysis. Although the murmur signal power varies in different recording positions on body surface, which can only cause variations in intensity, no obvious discrepancy is found in spectrum distribution. Thus, physical and pathological features of murmurs can be found through the study of TF distribution characteristics of cardiac murmurs.

The experiment results and theoretical analysis indicate that, although there are still many problems of cardiac murmur TF analysis to be solved in fundamental theory research and clinical diagnosis application, with the research work deeper and deeper, dynamic characteristics, which can deepen the knowledge about the acute mechanism of cardiac murmur, could be obtained through adaptive TF spectrum analysis. In spite, the TF spectrum not only distinguishes murmurs of different kinds intuitively, but also offers quantitative data, which are powerful tools to evaluate heart function and diagnose heart diseases.

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